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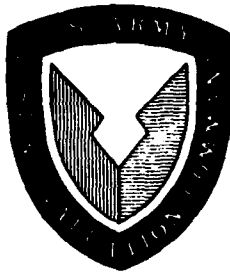UNCLASSIFIED APG-MT-5318   NL

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FINAL REPORT

RESEARCH AND DEVELOPMENT

OF

INSTRUMENTATION PROGRAM, EVALUATION OF A GENERAL

PURPOSE MUZZLE VELOCITY DOPPLER PROCESSOR,

THE DBA SYSTEMS, INC. INVITE 512

NOVEMBER 1979

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The test item is a commercially manufactured microprocessor-based general-purpose doppler processor for muzzle-velocity measurement. This project was to determine the suitability of the test item for proving-ground instrumentation. The evaluation was conducted at Aberdeen Proving Ground from 29 July 1977 through 27 September 1979. Field and laboratory tests were conducted. It is concluded that (1) the second-order least squares fit used by the INVITE does not provide the accuracy and precision required for proving-ground applications, (2) INVITE raw data processed separately using a first-order

20. least squares fit does provide the accuracy and precision required for proving ground applications (better than 0.1%), (3) the doppler quality-check circuitry of the INVITE does not function properly, and (4) as presently programmed, the flexibility of the INVITE is inadequate. It is recommended that (1) the test item be used for data acquisition only (not processing), (2) all processing be done with a first-order fit, and (3) no additional systems be purchased.

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ABSTRACT

The test item is a commercially manufactured microprocessor-based general-purpose doppler processor for muzzle-velocity measurement. This project was to determine the suitability of the test item for proving-ground instrumentation. The evaluation was conducted at Aberdeen Proving Ground from 29 July 1977 through 27 September 1979. Field and laboratory tests were conducted. It is concluded that (1) the second-order least squares fit used by the INVITE does not provide the accuracy and precision required for proving-ground applications, (2) INVITE raw data processed separately using a first-order least squares fit does provide the accuracy and precision required for proving ground applications (better than 0.1%), (3) the doppler quality-check circuitry of the INVITE does not function properly, and (4) as presently programmed, the flexibility of the INVITE is inadequate. It is recommended that (1) the test item be used for data acquisition only (not processing), (2) all processing be done with a first-order fit, and (3) no additional systems be purchased.

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FOREWORD

The Materiel Testing Directorate, US Army Aberdeen Proving Ground, was responsible for program planning, evaluation, and reporting. Mr. Ed Childers of the Naval Surface Weapons Center, Dahlgren, VA provided advice and assistance concerning operation of the test system.

SECTION 1. BODY

1. BACKGROUND

In the past decade, rapid changes in technology have increased the reliability and sophistication of muzzle-velocity radar (MVR). References 1, 2, and 3 describe evaluations of four different MVR systems that have been used by Army agencies. The recent procurement of the M-90 radar chronograph has added additional sophistication since this unit utilizes a microprocessor-based processor; however, all these systems lack flexibility as they are designed to work with a single microwave head and provide little or no adaptability in processing technique.

To overcome some of the disadvantages of these earlier systems, the Naval Surface Weapons Center, Dahlgren, VA, contracted to have a general-purpose muzzle-velocity doppler processor developed to their specifications. The contractor selected was DBA Systems, Inc. of Melbourne, FL. The final product was called the INVITE (Initial Velocity, Initial Trajectory Evaluation) System, model 512.

The measurement of velocity of artillery projectiles is a requirement for many test programs. Since the INVITE appeared to offer greatly improved performance and flexibility over existing processors, this project was initiated to purchase and evaluate the INVITE for proving-ground use.

2. DESCRIPTION OF TEST ITEM

A complete INVITE system consists of the model 512 processor manufactured by DBA plus any 80-column RS-232C compatible printer. For this evaluation a Texas Instruments model 743KSR printer was used. A picture of the processor is in figure 2.1.

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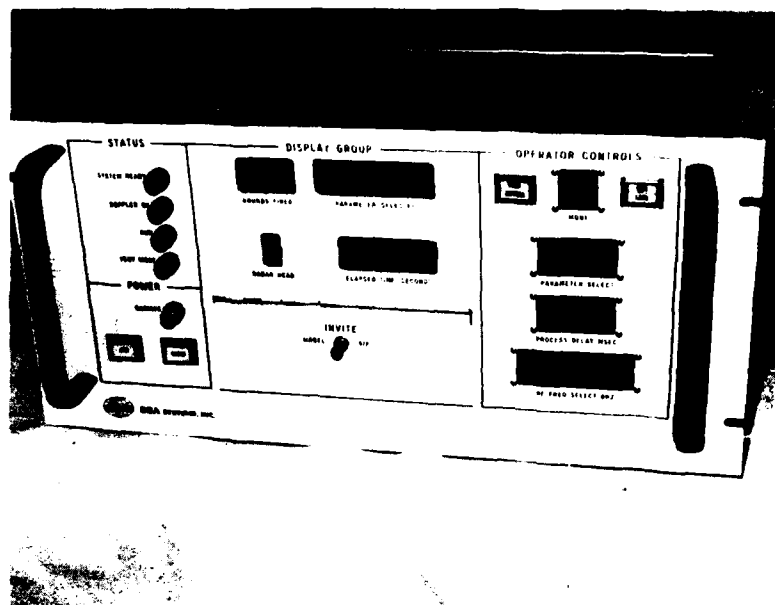Figure 2.1. DBA System, Inc. INVITE model 512.

A block diagram of the processor is in figure 2.2. The physical characteristics of the processor are:

    Size – 22.2 x 48.2 x 45.7 cm (8.75 x 19 x 18 in.)
    Weight – 20.4 kg (45 lb)
    Operating temperature – 0° to 70° C (32° to 158° F)
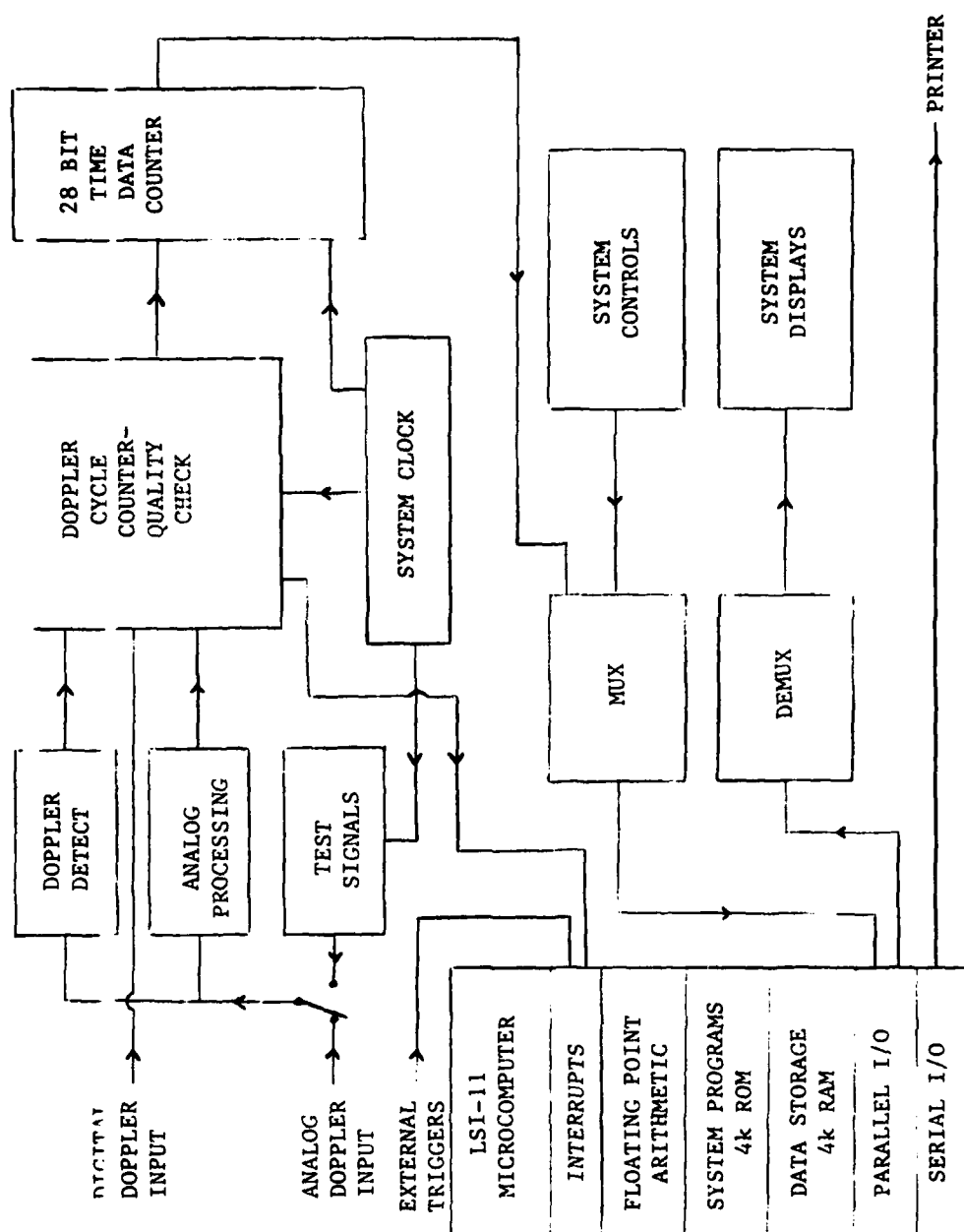   Power required – 117 VAC, 50 Hz, 3 A

Figure 2.2. Block diagram of the processor.

2 (Cont'd)

The processor is composed of four major assemblies:

a. System power supplies.

b. Digital Equipment Corp. LSI-11 microcomputer consisting of:

(1) CPU KD11-F with Floating Point Arithmetic option KEV-11 and 4 kilobytes of random access memory (RAM).

(2) 4-kilobyte RAM MSV11-B.

(3) 4-kilobyte high-speed bipolar programmable read-only memory (PROM) MRV11-AA.

(4) Duplex 16-bit parallel input/output (I/O) interface DRV11.

(5) Serial I/O interface DLV11.

(6) System backplane H9270.

c. DBA System, Inc., hardware mounted on three wire-wrapped circuit boards.

d. Front panel controls, indicators, and interface circuits.

A complete description of the processor hardware configuration is in reference 4. A complete description of the processor software configuration is in reference 5.

The processor provides the following operational modes:

a. Single Shot – processes 64 doppler samples; performs a second-order least-squares fit (SOLSF) on a maximum of 32 samples; calculates the standard deviation (SD) in the residuals (difference between the fit and measured velocities); throws out the largest residual if it exceeds three times the SD in the residuals; iterates twice if necessary; outputs to the printer: muzzle velocity (Vo), muzzle acceleration (Ao), muzzle jerk (Jo), SD of the residuals, time from external trigger to doppler detect, number of samples used in the fit, and eight-round moving muzzle-velocity average.

b. Rapid Fire – same as single shot except no iterations of the fit are performed. The maximum rate of fire is two rounds per second.

c. Velocity and Time List – same as single shot except that the velocity, time, and quality of all 64 samples are also printed. Approximately 90 seconds are required for this printout on the 743 KSR.

2 (Cont'd)

d. Raw Data List - no processing is performed; prints the period, time, and quality for the 64 samples.

e. Short Velocity Range Plot - velocity and range are calculated for the 64 samples; and prints the velocity, time, range, and quality for the 64 samples.

f. Long Velocity Range Plot - collects the first 64 samples in the normal manner; collects an additional 192 samples, each delayed by the process delay time; calculates velocity and range for the 256 samples; and prints the velocity, time, range, and quality for the 256 samples.

g. Statistics Module - takes no new data; provides average velocity and SD for any group of rounds in memory. Modes 1, 2, and 3 provide storage for up to 100 rounds.

h. Test Header - prints a test header for identification purposes.

i. System Diagnostic and Test Modes - allow controls and display indicators to be tested; provide three different test frequencies for checking the processor.

As presently programed the processor uses the entire 4 kilobytes of PROM; therefore, additional operational modes could be supported only through the addition of another PROM board or the deletion of existing modes. The MSV11-B 4-kilobyte RAM board is not used at all; therefore, additional storage of data could be accomplished without adding additional memory.

The following parameters may be input to the processor:

RF Frequency - frequency of radar head used.

Process Delay - delay from receipt of doppler to processing of first sample (0 to 999 msec).

Round Number - allows any number in range 1-100.

Doppler Cycle Count - the number of doppler cycles in a sample (1 to 4095).

Doppler Cycle Jitter - the amount of difference between the positive and negative halves of a doppler cycle (0 to 255).

Number of Failures - the number of cycles in a sample that must fail the jitter criteria before the sample is flagged bad (1 to 255).

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The processor will accept analog doppler with frequencies from 20 to 200 kHz and an amplitude of 20 mV to 5V p-p. Digital input in the form of a differential line driver (type 9614 or 7830) is also acceptable. The digital input is compatible with General Electric MVR-200 series radar heads.

Two additional external triggers are also provided to allow referencing the start of doppler to an external event. These inputs are labeled closed firing key (CFK) and infrared detect (IRD). They are transistor-transistor logic (TTL) compatible (active low).

Light-emitting diode (LED) displays are available on the front panel to display most of the information sent to the printer (although a printer is much more convenient). The PARAMETER SELECT switch is used to determine what information is to be displayed.

3. OBJECTIVES

The objectives of the evaluation were:

a. To determine that the accuracy and precision of the processor were adequate for use as proving-ground instrumentation.

b. To determine the utility of the processor as proving-ground instrumentation.

4. DETAILS OF THE EVALUATION

4.1 ANALOG INPUT CIRCUITRY

The analog input circuitry of the INVITE consists of the following sections:

a. An input amplifier with gain of 18.

b. A bandpass filter with a gain of 1.7, composed of an active high-pass and an active low-pass filter.

c. An additional open-loop operational amplifier stage.

d. A comparator to convert the analog signal into a digital signal.

Since no information was provided in the manual concerning the input voltage range, the properties of the analog input circuitry were investigated. A Wavetek model 145 signal generator was used to provide a 50-kHz sine-wave input to the INVITE. Voltages were measured at various points in the circuit using an oscilloscope. The results are in table 4.1.

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4.1 (Cont'd)

TABLE 4.1. VOLTAGE AND WAVEFORMS AT VARIOUS POINTS IN
THE ANALOG INPUT CIRCUITRY
(ALL VOLTAGES ARE P-P)

Input J9	Output of Input AMP (A3-3-14)	Output of Filter (A3-28-16)	Output of AMP (A3-27-10)	Output of Comparator (A3-39-11)
0.01	[a]0.18	0.3	[b]20.0	Applies to all input values:
0.05	0.9	1.45	21.0 trapezoidal wave with 2.8 μsec rise and fall	5V TTL signal.
0.1	1.7 distorted	2.95	21.0 trapezoidal wave with 2.4 μsec rise and fall	0 corresponds to pos input
0.5	5.6 distorted	6.0 triangle	21.0 trapezoidal wave with 2 μsec rise and fall	0.2 μsec rise, 0.1 μsec fall.
1.0	7.5 distorted	6.0 triangle	21.0 trapezoidal wave with 2 μsec rise and fall	0.003V in is minimum signal that generates a reliable output.
2.0	9.6 distorted	6.0 triangle	21.0 trapezoidal wave with 2 μsec rise and fall	

[a]All values in this column have 0.05V at 500 kHz noise.
[b]Values below 0.02 generate a haversine with base at -10V.
[c]Distortion starts at 0.15.

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An additional test was made using the SYNC OUT signal from the
signal generator to trigger the oscilloscope while looking at the output
of the comparator. Rise-time jitter was approximately 0.2 microsecond
and fall-time jitter was less than 0.1 microsecond for all inputs greater
than 0.018V p-p; thus, although the input amplifier and filter introduce
noise and severe distortion, they do not affect the timing of the input
waveform.

The input connector J9 also serves as a source of noise. High-
frequency noise, apparently generated by digital logic transitions, is
observable at J9. The amplitude is sufficient (some components are 0.035V
p-p) to interfere with other devices connected to the input. Even if the
input is terminated in 50 ohms the amplitude is only slightly reduced.
This suggests that the input amplifier is serving as the source of the
noise.

4.2 BENCH TESTS

The INVITE has test modes that can be used for diagnostic or
confidence tests. Some tests use a fixed frequency (choice of 25, 50,
or 75 kHz) to simulate a doppler input. This test signal does not check
the system completely since it does not slew in frequency, change in
amplitude, or introduce noise. To overcome these deficiencies a bench-
test system was assembled using standard laboratory instruments. A block
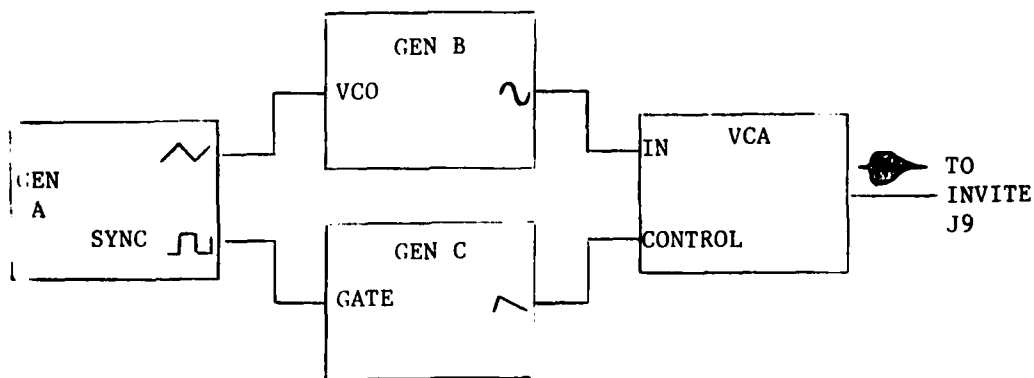diagram of the test system is in figure 4.2-1.

Figure 4.2-1. Block diagram of instruments used to bench test
INVITE.

The instruments used have the following characteristics:

GEN A – a function/noise generator capable of producing a triangle
          wave with a controllable amount of noise and corresponding
          sync signal, which is low on the positive slope portion of
          the triangle wave.

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4.2 (Cont'd)

GEN B - a function generator capable of producing a sine wave whose frequency can be controlled by an externally applied voltage (VCO or external FM input).

GEN C - a function generator with DC offset capable of producing a ramp waveform, which can be gated on .or off by an external voltage.

VCA - a voltage-controlled amplifier whose gain can be varied from 1 to 100 by a control voltage.

GEN B produces a sine wave to simulate a doppler signal. GEN A produces a ramp with noise that frequency modulates GEN B to produce a decreasing frequency sweep with frequency jitter. This signal simulates the decreasing velocity of a round. GEN C produces a negative-slope ramp when it is gated on by the sync waveform from GEN A. The gating ensures that GEN A and GEN C are locked together. The output of GEN C controls the gain of the VCA to produce an amplitude modulation envelope for the output of GEN B. Since the transfer function for the VCA is not linear, the envelope produced resembles the envelope of a round and is not linear. In addition, the VCA is operated at high gain so that amplitude noise is also added to the signal.

By making the proper choices of frequencies and amplitudes of waveforms, a wide variety of velocity and deceleration combinations can be programed. Only a limited range of amplitude-modulation envelopes is possible with the system described; nevertheless, the test system is useful for evaluating qualitative performance and gaining experience with parameter settings. However, since it is composed of analog instruments, it is not capable of determining accuracy and precision.

4.3 RADAR HEADS USED

Since the INVITE is a processor only, it must be combined with a doppler radar head to form a complete system. Two different heads were used during the evaluations: the General Electric MVR-203 and the Lear Siegler DR-810.

The MVR-203 provides an analog output on the head (BNC jack). The output voltage was 10V p-p maximum, with extensive limiting. The output of the MVR-210 was fed to an Ithaco 4312 active filter set to operate in a bandpass mode with the center frequency of the bandpass set near the expected doppler frequency. The output of the filter goes to the input of the INVITE.

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The DR-810 provides a buffered, filtered analog output at J2 on the processor front panel (pin W - external filtered analog doppler, pin X - analog ground). The output was 10V p-p maximum. The output of the DR-810 goes directly to the input of the INVITE.

The TRIGGER THRESHOLD was adjusted to provide reliable operation with the particular head used.

4.4   INITIAL FIELD TESTS

An initial test was carried out to determine that the unit was functioning properly. This test was conducted using an MVR-203 radar head mounted on a 155-mm self-propelled howitzer, M109. Of 14 rounds fired, five were flagged as bad readings (positive muzzle acceleration - Ao). In addition, the Ao values for the nine unflagged rounds ranged from -71.5 to -158.0 m/sec^2. This is a much larger variation than would normally be expected. The MODE 3 printout indicated velocity samples that looked adequate to provide a good fit.

A second test was conducted using the DR-810 head on the same weapon. Forty-five rounds were fired. Of this number 22 were flagged as bad (positive Ao), 16 were not flagged, and 7 were missed for other reasons. The DR-810 processor provided velocities for all 45 rounds. The Ao values for the 16 unflagged rounds ranged from 0 to -178 m/sec^2. Again, this is a much larger variation than was expected and the MODE 3 printout indicated adequate data.

4.5   EVALUATION OF THE FIT

Since the MODE 3 printout indicated that adequate data were available, an evaluation of the fit was made. A program was written (appendix B) for a Hewlett-Packard 9825 calculator to simulate the SOLSF used by the INVITE. A second program was written to input the data from the MODE 3 printout to magnetic tape. The SOLSF parameters generated by the 9825 agreed closely with the values calculated by the INVITE. The floating point resolution of the LSI-11 is eight digits; the 9825 is twelve digits, so some difference can be expected.

Another program was written to perform an FOLSF on the data. The FOLSF parameters calculated by the 9825 differed from the SOLSF parameters. Table 4.5-1 lists the values obtained from the two computations, the INVITE, the DR-810, and some comparisons for ten rounds. The values of Ao obtained with the FOLSF are very consistent compared to the values obtained with the SOLSF. Based on the average difference and standard deviation in difference, the FOLSF Vos are in better agreement with the DR-810 Vos than the SOLSF.

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TABLE 4.5-1. COMPARISON OF DIFFERENT FITS
(Vo in m/sec; Ao in m/sec2)

Rd No.	INVITE Fit		9825 2nd-Order Fit		9825 1st-Order Fit		DR-810	Difference in Vo	
	Vo[a]	Ao	Vo	Ao	Vo	Ao	Vo	DR810-9825 1st Order	DR810-9825 2nd Order
2958	-785.8	40	785.8	30.9	788.1	-27.9	789.1	1.0	3.3
2961	-787.5	-12	787.2	2.2	788.6	-33.8	789.2	0.6	2.0
2962	-787.0	24	787.2	4.9	788.5	-28.7	789.8	1.3	2.6
2964	-789.0	16	789.0	6.3	790.6	-32.1	791.3	0.7	2.3
2965	-786.6	22	787.3	14.5	789.3	-32.9	789.9	0.6	2.6
2966	-789.1	24	789.1	29.7	791.7	-33.0	791.9	0.2	2.8
2967	-788.0	44	788.3	37.9	791.3	-34.4	791.8	0.5	3.5
2968	790.5	-36	790.1	-19.8	790.5	-30.8	791.3	0.8	1.2
2969	-789.2	8	789.5	5.7	790.9	-29.5	791.7	0.8	2.2
2970	-789.9	24	790.1	20.0	792.1	-30.1	792.9	0.8	2.8
Avg value	-	-	-	13.2	-	-31.3	-	0.7	2.5
Std dev	-	-	-	16.2	-	2.1	-	0.3	0.6

[a] The minus sign for Vo indicates a flagged value: positive Ao or more than two iterations required to fit.

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4.5 (Cont'd)

To examine more closely the difficulty with the SOLSF, an additional program was written (appendix B), which introduced a controlled amount of noise. The noise was generated by the random-number generator function of the 9825. The generated data were of the form V_i = round $[V_o + A_oT_i] + N$

where

V_o = 800 m/sec, A_o = -40 m/sec^2
N = round $[(random No. -0.5)*G]$
G = noise factor
round = round function (to 2 decimal places).

Since the random-number generator produces a different set of values each time the program is run, three data files were created for each case. The range of T_i was varied to provide three general cases:

a. Range 0.0612-0.0984 second with a step of 0.0012 second. This case represents the data acquisition process described in 4.1. The data acquisition time is less than the delay time from the muzzle to the start of data.

b. Range 0.0648-0.2136 second with a step of 0.0048 second. The data acquisition time is greater than the delay time from the muzzle to start of data.

c. Range 0.0000-0.0372 second with a step of 0.0012 second. The muzzle overlaps the data acquisition range.

The data files were processed using the FOLSF and the SOLSF. The fit parameters for the three time ranges and values of noise factor of 0, 0.4, and 1 are in table 4.5-2. The value of G = 0.4 corresponds to a root-mean-square (RMS) noise amplitude of 0.1 m/sec; G = 1 corresponds to an RMS noise amplitude of 0.3 m/sec.

Table 4.5-2 shows that for case a small amounts of noise can introduce large deviations in V_o and A_o. For cases b and c the deviation of V_o is not large; however, the deviation of A_o is still significant.

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4.5 (Cont'd)

TABLE 4.5-2. PROCESSED CALCULATOR-GENERATED DATA
(Vo in m/sec, Ao in m/sec²)

Time Data Range (sec)	Time Step (sec)	G = 0				G = 0.4				G = 1			
		FOLSF		SOLSF		FOLSF		SOLSF		FOLSF		SOLSF	
		Vo	Ao	Vo	Ao	Vo	Ao	Vo	Ac	Vo	Ao	Vo	Ao
0.0612-0.0984	0.0012	800.0	-40.0	800.0	-39.4	799.9	-39.1	800.5	-52.8	800.1	-41.5	795.8	69.8
						800.0	-40.5	800.8	-60.3	800.3	-42.8	799.1	-12.6
						799.9	-39.1	801.1	-68.9	800.6	-46.5	796.6	55.3
0.0648-0.2136	0.0048	800.0	-40.0	800.0	-40.1	800.0	-40.4	800.0	-39.1	799.9	-39.3	799.5	-32.3
						800.0	-40.3	800.2	-43.3	800.3	-41.4	800.1	-39.6
						799.9	-39.4	800.0	-39.7	800.0	-40.8	799.6	-34.1
0.0000-0.0372	0.0012	800.0	-40.1	800.0	-39.9	800.1	-42.6	800.1	-47.0	800.1	-37.5	800.1	-43.0
						800.0	-39.2	799.9	-30.5	800.1	-43.4	800.1	-47.9
						800.0	-39.8	800.0	-34.9	799.9	-37.5	800.1	-69.1

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Additional simulated data files were generated for case a, which had G=1 noise added and which rounded Vi to one, two, and five digits after the decimal place. The different number of digits after the decimal point represent different resolutions of the INVITE. The results obtained from the simulated data are in table 4.5-3.

TABLE 4.5-3. PROCESSED CALCULATOR-GENERATED DATA
FOR CASE a WITH G=1 (Vo in m/sec; Ao in m/sec^2)

No. of Digits after Decimal Point	FOLSF		SOLSF	
	Vo	Ao	Vo	Ao
5	799.8	−37.1	797.3	27.5
	800.5	−45.4	799.9	−28.9
	800.1	−46.5	797.7	19.8
	799.8	−37.0	797.3	28.2
2	800.5	−45.6	799.8	−27.6
	800.1	−43.3	797.7	19.8
	799.8	−37.5	798.2	4.5
1	800.5	−46.1	800.6	−47.8
	800.2	−43.6	798.1	10.2
1 (No Noise Added)	800.0	−40.3	800.7	−58.4

The values in the table show that various resolution values do not appreciably change the fit parameters for the FOLSF; however, when the resolution approaches 0.1 m/sec the SOLSF is affected.

4.6 INPUT PARMETER SETTINGS

It was shown in the previous paragraph that when the resolution of the velocity data reached 0.1 m/sec a SOLSF would be affected. The resolution of the INVITE can approach 0.1 m/sec under some conditions. The doppler frequency f_D is given by

$$f_D = \frac{2f_m}{c} V$$

where c is the speed of light

f_m is the microwave frequency

V is projectile velocity.

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4.6 (Cont'd)

For the INVITE the resolution of the crystal oscillator is 0.1 microseconds, which is sufficiently small so that the resolution equation can be determined by taking the derivative of the doppler equation. The INVITE measures the doppler frequency by determining the period T for N cycles.

Then
$$\frac{N}{T} = \frac{2\,f_m}{c}\,V$$

and the resolution is

$$dV = \frac{-2\,f_m}{Nc}\,V^2\,dT$$

The number of cycles used in a measurement can be varied from 1 to 4,095 by a front panel switch.

For an SOLSF, if the resolution is not to affect the fit, dV should be less than 0.01 m/sec.

Then $N = 0.000702\ V^2$ (10.525 GHz)

or $N = 0.00109\ V^2$ (16.45 GHz).

For the FOLSF the resolution should ideally be 0.01% of the velocity level.

Then $N = 0.0702\ V$ (10.525 GHz)

or $N = 0.109\ V$ (16.45 GHz).

In addition to determining the resolution, N also determines the measurement time required. As the measurement time increases so does the distance the round travels. If N is set too large, the later samples will not be usable. The distance the round travels is:

$$d = V*t_D + 0.014*N*S \quad (10.525\ \text{GHz})$$

or $d = V*t_D + 0.0091*N*S$ (16.45 GHz)

where V is the expected velocity

   t_D is the processor delay time, and

   S is the number of samples.

The processor requires at least six good samples before it will perform a fit.

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An additional factor that must be considered is the time required
by the microprocessor to process the data for each sample. This time
is 400 microseconds. N must be large enough so the N/f_D is greater
than 400 microseconds. If it is not, velocities will be 1/2, 1/3, 1/4,
... of the expected value. The operator must balance resolution, number
of samples, and processing time when setting N.

The processor delay can be determined by using the MODE 3 printout
to determine the time at which the velocities become consistent.

The settings for the doppler cycle jitter and number of failures
can be determined by using the MODE 3 printout. Settings that are
too low will flag all data as bad. See paragraph 4.7 for an additional
discussion of this point.

4.7 DOPPLER QUALITY CHECK

A hardware check is performed to determine the quality of the doppler
signal. If a sample fails, the quality check is flagged and is not used
in the analytical fit. The hardware check is described in reference 4;
it consists of counting the number of clock cycles required for the
positive half of a cycle and for the negative half of a cycle and then
comparing the two counts. The value of the allowable difference
(called doppler cycle jitter - DCJ) and the number of failures (NFAIL)
allowed in a sample are input from the front panel.

During the various phases of testing the following abnormalities
were noted:

a. The values of DCJ and NFAIL required to obtain unflagged data
were always much larger than intuition or the nominal values suggested
by reference 4.

b. Many samples are flagged bad even though their velocities
appear valid when compared to adjacent samples.

c. Many samples that are not flagged bad have velocities which
are significantly different from adjacent samples.

A series of bench tests were performed to evaluate the operational
characteristics of the quality-check hardware. An Interface Technology
model RS-648 word/timing generator was used to generate a precision
input signal for the INVITE. The circuit used is shown in figure 4.7-1.
The input to the INVITE was a square wave with rise and fall times less
than 0.01 microsecond. The RS-648 clock is 20 MHz and the positive and
negative portions of a cycle can be adjusted to a resolution of 0.1
microsecond. A frequency of 50 kHz was used.

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4.7 (Cont'd)

```
                          100        0.3uF
  ┌──────────────┐      ─/\/\─  ──┤├──            TO
  │ RS-648    ⊔⊓ │──────────┬────────┬──────→  INVITE
  │              │        5.1│     100│           J9
  └──────────────┘──────────┴────────┴──────→
```
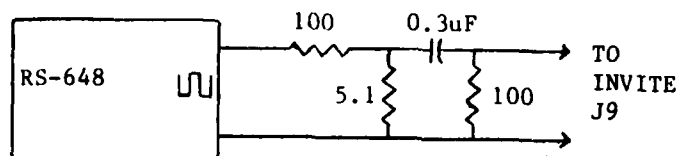
Figure 4.7-1. Test setup for hardware doppler quality circuit.

Initially the periods of the positive and negative cycles were set equal and the values of DCJ and NFAIL increased until 90% of the samples were acceptable. Sixty-four doppler cycles per sample were used. Table 4.7-1 lists the results.

TABLE 4.7-1. PERCENTAGE OF ACCEPTABLE SAMPLES FOR VARIOUS DOPPLER COUNT JITTER (DCJ) AND NUMBER OF FAILURES (NFAIL) SETTINGS WITH A SYMMETRIC INPUT SIGNAL

| | DCJ | | | | |
NFAIL	4	6	8	10	12
1			78	59	100
2			97	91	
3	0	29	97	100	
6	9				
8		35			
12	3	78			
16		91			
24	10				
32	0				
48	58				
64	97				

It is interesting to note that for DCJ=4 and NFAIL=64, the percentage is not 100. Since there were 64 cycles per sample, NFAIL=64 should pass every sample regardless of the value of DCJ.

A second set of tests was performed using asymmetrical waveforms with constant settings of DCJ (12) and NFAIL (1). The tests were carried out with the positive cycle longer and then with the negative cycle longer. The results are in table 4.7-2.

TABLE 4.7-2. PERCENTAGE OF ACCEPTABLE
SAMPLES FOR VARIOUS ASSYMMETRIC
INPUT SIGNALS

Asymmetry			
Δt (μsec)	Percentage of Total Period	Positive Cycle Longer	Negative Cycle Longer
0.2	1	71	100
1.0	5	3	100
2.0	10	0	91
3.0	15	0	91
4.0	20	0	0

It is apparent that the doppler quality circuit does not function adequately since it does not flag as unacceptable asymmetric waveforms with a longer negative cycle.

4.8 ACCURACY AND PRECISION

It was shown in paragraph 4.5 that the INVITE SOLSF was not adequate for processing data. For this reason, an accuracy and precision firing test as specified in reference 6 using two sets of comparison standards was not conducted; however, an estimate of the accuracy and precision capability can be determined by processing the MODE 3 data printouts with an FOLSF calculator program and comparing these velocities to those obtained by a DR-810. Twenty rounds from the 20 July 1979 test firing were processed in this manner. The results are in table 4.8-1.

TABLE 4.8-1. COMPARISON OF INVITE MODE 3 DATA
PROCESSED WITH A FIRST-ORDER LEAST-SQUARE
FIT AND DR-810 MUZZLE VELOCITIES

Rd No.	DR810 (m/sec)	INVITE (m/sec)	ΔV (m/sec)	Rd No.	DR810 (m/sec)	INVITE (m/sec)	ΔV (m/sec)
2940	788.9	788.1	0.8	2958	789.1	788.1	1.0
2941	787.6	786.8	0.8	2961	789.2	788.6	0.6
2942	791.4	790.4	1.0	2962	789.8	788.5	1.3
2943	788.8	787.7	1.1	2964	791.3	790.6	0.7
2944	788.4	787.2	1.2	2965	789.9	789.3	0.6
2946	789.2	787.9	1.3	2966	791.9	791.7	0.2
2947	789.2	788.3	0.9	2967	791.8	791.3	0.5
2948	788.9	787.9	1.0	2968	791.3	790.5	0.8
2949	789.2	788.3	0.9	2969	791.7	790.9	0.8
2950	790.1	789.1	1.0	2970	792.9	792.1	0.8

The average difference between the two instruments is 0.87 m/sec and the standard deviation in the differences is 0.26 m/sec. These values are consistent with both instruments, having an accuracy of less than 0.1% and a precision of less than 0.1%.

4.9 MODIFICATIONS

Since the INVITE program is written in LSI-11 assembly language and stored in PROM, changes in the program cannot easily be made. To make the INVITE more readily usable it was decided that a direct interface to a 9825 would increase the utility of the INVITE.

The interface was implemented by using the Hewlett-Packard 98036A serial interface for the 9825 to replace the 743 KSR printer. A program was written to receive the data from the INVITE and format it for processing by the 9825. Since there is no handshaking involved between the INVITE and its printer port, all data transfers must be handled at the rate and time determined by the INVITE. The data rate for the 743 KSR is fixed at 300 baud; however, the 9825 and INVITE are capable of 9,600 baud. A switch was added to the DLV11 serial interface board to allow different baud rates to be quickly selected. An adapter cable between the 98034 and INVITE was fabricated as shown in figure 4.9-1.

9825	INVITE	
1	1	Amphenol type
2	3	17-90250-15
3	2	connector each end
7	7	
20	20	

Figure 4.9-1. 9825 to INVITE interface adapter cable.

A program was written to take the MODE 3 printout information, store the data on the 9825 cassette tape, print the data on the 9825 printer, process the data using an FOLSF, and print the results. The program also provides input of offset and setback of the radar head to allow the correction for nonradial doppler to be made. In addition, a descriptive header and comments are available for each round, the values of the maximum number of iterations and maximum and minimum numbers of points required for processing may be changed, and the round number may be four digits. A copy of the program is included in appendix B.

4.10 OTHER FACTORS

In addition to the inadequacy of the SOLSF, the noise generated by the input, and the improper operation of the hardware quality check, there are a number of other minor problems:

a. MODE 3 printout sample one is a large velocity at zero time but sample two is zero velocity at time one-half the delay. Both are flagged as invalid readings and neither is used in the processing; however, neither value serves any useful purpose in being printed. The MODE 3 printout should not contain these two samples.

b. In MODE 3 if the INVITE receives a false trigger before the real signal, it starts the printout process. To stop the printout and reset the unit, the RUN/LOAD switch must be cycled and a header printed. This process requires 5 to 10 seconds. Numerous rounds were missed because of this. In addition, the rounds counter is reset. A separate reset is required to allow recovery from a false trigger.

c. The flagging of rounds as failed if Ao is positive is not needed. Rounds should be flagged only if they do not produce a satisfactory fit.

d. Although not essential, it is of interest to know which samples were thrown out during iterations of the fitting process.

e. It is more logical to print the number of samples used in a fit rather than the number not used.

f. The number of significant digits used in the printouts is excessive. One digit after the decimal point is all that can be justified based on the resolution and accuracy of the equipment.

g. The RUN/LOAD and FEET/METERS switch/light assemblies should be replaced with separate switches and indicator lights. The present assemblies do not function properly.

h. The T/CFK and T/IRD inputs are configured such that if only one has been pulsed, then additional pulses on that input will reset the time; however, if both inputs have been pulsed, then additional pulses on either or both inputs will not reset the time.

i. Reference 5 states that at least eight samples are required before a fit will be attempted. Several cases were found where the fit was performed when only six samples were available.

j. Numerous differences were found between the schematic for the analog input circuitry (reference 4) and the actual circuit.

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4.10 (Cont'd)

k. Occasionally when power is applied the INVITE will not perform properly. The power must be turned off and on again to get the unit working properly.

ℓ. The printouts contain a number of nonprinting control characters, which serve no useful purpose. They should be eliminated from the print-out.

m. Occasionally samples are listed as having a zero velocity (particularly samples 35 and 63). The value stored in the memory is zero.

n. There is no cosine correction factor to account for the offset of the radar head from the gun.

o. Several user switches, adjustments, and test points are located under a door on the front panel of the INVITE. The door opens upwards and there is no catch to hold it. This makes adjustments difficult, as one hand must be used to hold the door open.

p. The test points for the doppler threshold and test-signal amplitude are on a component carrier, which plugs into a socket. When voltmeter probes are plugged into the test points, the weight pulls the carrier out of the socket.

q. The rotor of the doppler threshold adjustment potentiometer goes directly to the doppler threshold test point. Since the potentiometer is relatively high impedance (10 kohm), the line can be loaded by an external voltmeter.

The factors listed above can be described as annoying, but not devastating in their effect. There is one more factor that is devasting in terms of overall performance; this factor is that a number of important parameters are not available to the operator. These parameters are stored in PROM and cannot be altered by the operator. In particular, they include:

Maximum number of samples to be used.

Minimum number of samples to be used.

Mode time out.

Number of iterations allowed.

The ability of the operator to control these parameters is essential for complete flexibility in processing.

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The so-called rapid-fire mode was not tested since its maximum
rate of two rounds per second is much slower than desired. The utility
of the INVITE would be greatly increased if this mode were made to
function by storing a limited number of samples (approximately ten) for
20 rounds in the RAM and then processing after all rounds are fired.
The extra RAM card provides the necessary memory space.

The statistical mode was not used. Its capabilities are normally
not required on the range. The test modes were found to be useful for
checkout and testing. The long velocity range plot can be used with the
HAWK radar to provide instrumental velocity and range as a function of
time. The raw data list and short velocity range plot were not tested.

The time required by the system to store each sample is 400
microseconds. This time limits the number of cycles for each sample to
be larger than 0.0004 sec x f_D. This limitation means that projectiles
with very short doppler signals cannot be handled. This is a major
shortcoming of the system.

4.11 COMMENTS

The INVITE was purchased to provide increased flexibility as
compared to other muzzle-velocity radar systems. In fact, the INVITE
does not possess the flexibility required. The problem stems more from
the software of the system rather than the hardware. A number of alter-
natives exist that would provide the increased performance desired.
They are:

a. Rewrite the INVITE software so that all system parameters are
stored in the RAM instead of the PROM so that they can be accessed by
the operator. This maintains the stand-alone nature of the system, while
providing greater flexibility; however, the system would still be limited
by its stored program capabilities.

b. Add a disk drive or bubble memory containing a BASIC operating
system. Rewrite the PROM software for minimum data acquisition and
control functions with system parameters stored in the RAM. All
processing would be carried out with BASIC programs so that maximum
flexibility could be achieved. The addition of a disk drive or external
memory would increase the size and weight of the system, making
transportability in the field a problem.

c. Use a 9825 programmable calculator to provide the processing
capability of the system. The PROM software would be rewritten for
minimum data acquisition and control functions, with system parameters
stored in the RAM. This approach also makes field transportability a
problem.

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d. Both a and b or a and c could be implemented to provide a stand-alone system when required or a flexible processor when required.

5. CONCLUSIONS

It is concluded that:

a. The second-order least squares fit used by the INVITE does not provide the accuracy and precision required for proving-ground applications (para 4.5).

b. INVITE raw data processed separately using a first-order least squares fit does provide the accuracy and precision required for proving-ground applications (better than 0.1%) (para 4.8).

c. The doppler quality-check circuitry of the INVITE does not function properly (para 4.7).

d. As presently programmed, the flexibility of the INVITE is inadequate (para 4.10).

6. RECOMMENDATIONS

It is recommended that:

a. The INVITE be used for data acquisition only (not processing).

b. All processing of INVITE data be carried out using a first-order least-squares fit.

c. Additional systems not be purchased.

APPENDIX A - REFERENCES

1. Francis, C. L., Final Report of Special Study, Evaluation of
   MEDOVIC Radar, TECOM Project No. 9-CO-111-EFM-001, Report No.
   APG-MT-4519. US Army Aberdeen Proving Ground, September 1974.
   (Distribution controlled by US Army Test and Evaluation Command,
   ATTN: AMSTE-RU.)

2. Francis, C. L., Final Report, Evaluation of Solid State Radars for
   Measuring Projectile Velocity, TECOM Project No. 5-CO-APO-SSR-201,
   Report No. APG-MT-4754. US Army Aberdeen Proving Ground, April 1976.
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3. Fogle, B. L., Final Report, RDI Program Evaluation of Radar
   Velocimeter, TECOM Project No. 5-CO-APO-VEL-601, Report No.
   APG-MT-4882. US Army Aberdeen Proving Ground, October 1976.
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4. "Operation and Maintenance Manual, Initial Velocity, Initial
   Trajectory Evaluation (INVITE) System, Model 512." DBA Systems, Inc.

5. "System Software Manual, Initial Velocity, Initial Trajectory
   Evaluation (INVITE) System, Model 512." DBA Systems, Inc.

6. Standardization Agreement (STANAG) No. 4114 (Edition 2), Measurement
   of Projectile Velocities, North Atlantic Treaty Organization,
   29 October 1973.

APPENDIX B - CALCULATOR PROGRAMS

Program 1 - Data Entry

```
    "DBA Processor Data Entry Program":
1:  dim V[32],T[32],Q[32],N,A$[32]
2:  fmt 1,f6.1,3x,f8.6
3:  "CMT:Enter velocity in mps":
4:  "CMT:Enter time in microseconds":
5:  "CMT:Enter only rnds with Q=1. Others will be set to 0 automatically":
6:  ent "Tape header=?",A$
7:  ent "N=?",N
8:  for I=1 to N
9:  ent V[I]
10: ent T[I]
11: T[I]/1000000→T[I]
12: 1→Q[I]
13: wrt .1,V[I],T[I]
14: stp
15: next I
16: ent "Record on file no?",F
17: rcf F,V[*],T[*],Q[*],N,A$
18: dsp "DONE!!!!!!!!!!!!!!!"
19: end
```

Program 2 - Second Order Fit

```
    "CMT:9825 simulation of DBA subrtn POLY":
1:  dim V[32],T[32],Q[32],N,A$[32],N[3,3],C[3],F[3],R[32]
2:  fmt 1,f2.0,x,f6.1,x,f6.0
3:  ent "File to be analyzed",F
4:  ldf F,V[*],T[*],Q[*],N,A$
5:  spc 4
6:  prt "    2nd Order"
7:  prt " DBA SIMULATION"
8:  spc
9:  prt A$
10: spc
11: prt "RND  VEL  TIME"
12: prt "NO  (MPS) (uSEC)"
13: for I=1 to N
    wrt 16.1,I,V[I],T[I]*1000000
    next I
```

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```
16: "CMT:Perform 2nd order lst sqs fit":
17: 0→N[1,1]
18: 0→N[1,2]
19: 0→N[1,3]
20: 0→N[2,3]
21: 0→N[3,3]
22: for I=1 to H
23: N[1,1]+Q[I]→N[1,1]
24: N[1,2]+T[I]*Q[I]→N[1,2]
25: N[1,3]+T[I]↑2*Q[I]→N[1,3]
26: N[2,3]+T[I]↑3*Q[I]→N[2,3]
27: N[3,3]+T[I]↑4*Q[I]→N[3,3]
28: next I
29: N[1,2]→N[2,1]
30: N[1,3]→N[2,2]
31: N[1,3]→N[3,1]
32: N[2,3]→N[3,2]
33: inv N→N
34: 0→C[1]
35: 0→C[2]
36: 0→C[3]
37: for I=1 to H
38: C[1]+V[I]*Q[I]→C[1]
39: C[2]+V[I]*T[I]*Q[I]→C[2]
40: C[3]+V[I]*T[I]↑2*Q[I]→C[3]
41: next I
42: mat N*C→F
43: spc
44: fxd 1
45: prt "Vo=",F[1],"Ao=",F[2],"Jo=",F[3]
46: "CMT:Calculate residuals and stnd dev in rsdls":
47: 0→B
48: 0→C
49: 0→R
50: 0→M
51: for I=1 to H
52: if Q[I]=0;0→R[I];gto 58
53: V[I]-(F[1]+F[2]*T[I]+F[3]*T[I]↑2)→H
54: abs(H)→R[I]
55: if R[I]>R;R[I]→R;I→M
56: C+Q[I]→C
57: B+R[I]↑2→B
58: next I
59: (B/(C-3))↑.5→S
60: fxd 2
61: prt "SIGMA=",S
62: S*3→S
63: prt "Lgst rsdl=",R
64: fxd 0
65: prt "# lgst rsdl=",M
66: if R<S;stp
67: 0→Q[M]
68: gto 17
69: end
```

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Program 3 - First Order Fit

```
 1:  "CMT:9825 simulation of DBA using 1st order fit":
 1:  dim V[32],T[32],Q[32],N,A$[32],F[3],R[32]
 2:  fmt 1,f2.0,x,f6.1,x,f6.0
 3:  ent "File to be analyzed",F
 4:  ldf F,V[*],T[*],Q[*],N,A$
 5:  spc 4
 6:  prt "    1st Order"
 7:  prt " DBA SIMULATION"
 8:  spc
 9:  prt A$
10:  spc
11:  prt "RND  VEL   TIME"
12:  prt "NO  (MPS) (uSEC)"
13:  for I=1 to N
14:  wrt 16.1,I,V[I],T[I]*1000000
15:  next I
16:  "CMT:Perform 1st order lst sqs fit":
17:  0→Q
18:  0→T
19:  0→U
     0→V
     0→W
     for I=1 to N
     Q+Q[I]→Q
     T+T[I]*Q[I]→T
25:  W+T[I]↑2*Q[I]→W
26:  U+T[I]*V[I]*Q[I]→U
27:  V+V[I]*Q[I]→V
28:  next I
29:  (U-V*T/Q)/(W-T*T/Q)→F[2]
30:  (V-F[2]*T)/Q→F[1]
31:  spc
32:  fxd 1
33:  prt "Vo=",F[1],"Ao=",F[2]
34:  "CMT:Calculate residuals and stnd dev in rsdls":
35:  0→B
36:  0→C
37:  0→R
38:  0→M
39:  for I=1 to N
40:  if Q[I]=0;0→R[I];gto 46
41:  V[I]-(F[1]+F[2]*T[I])→H
42:  abs(H)→R[I]
43:  if R[I]>R;R[I]→R;I→M
44:  C+Q[I]→C
45:  B+R[I]↑2→B
46:  next I
```

Program 3   (continued)

```
47: (B/(C-3))↑.5→S
48: fxd 2
49: prt "SIGMA=",S
50: S*3→S
51: prt "Lost rsdl=",R
52: fxd 0
53: prt "# lost rsdl=",M
54: if R<S;stp
55: 0→Q[M]
56: sto 17
57: end
```


Program 4 - Simulated Data

```
0: "CMT:Simulated Data Generator Program":
1: dim V[32],T[32],Q[32],N,A$[32]
2: ent "Tape header=?",A$
3: ent "No. of smpls=?",N
4: ent "Noise gain=?",G
5: 800→V
6: -40→A
7: fxd 2
8: for I=1 to N
9: .06+.0012*I→T[I]
10: V+A*T[I]→V[I]
11: prnd(V[I],-2)→V[I]
12: prnd((rnd(1)-.5)*G,-2)→H
13: V[I]+H→V[I]
14: 1→Q[I]
15: prt H
16: next I
17: ent "Record on file no?",F
18: rcf F,V[*],T[*],Q[*],N,A$
19: dsp "DONE!!!!!!!!!!!!!!!!"
20: end
```

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Program 5 - INVITE/9825 Interface

```
0:  "CMT:INVITE/9825 Interface/Processing Program":
1:  dim V[64],T[64],A$[32],P[11],Q[64],R[62]
2:  dim C$[32],D$[1],Q$[64],U$[1],N[64]
3:  10+J
4:  8+K
5:  32+L
6:  0+Z
7:  fmt 1,/,5x,f2,3x,f3,8x,f4,1x,f5,3/
8:  fmt 2,6x,c1,41x,f5,x,f5,3/
9:  fmt 3,x,f3,4x,f10,3x,f9,3x,c1
10: fmt 4,f2.0,f7.1,x,f6.0
11: fmt 5,7x,c1,41x,f5,x,f5,3/
12: fmt 6,"NO  (",c1,"PS) (usec)"
13: fmt 7,"TRK",f1.0,x,"FILE ",f3.0
14: fmt 9,"T=",f5.0,";T1=",f5.0
15: ldk 0
16: spc 4
17: prt "INVITE/9825 Data","Input/Processing","Program  12AUG79"
18: spc
19: dsp "Insert data tape-then CONTINUE"
20: stp
21: "CMT:Get input parameters":
22: "CMT:Data files must be at least 1200 bytes":
23: "CMT:Maximum 100 files per track":
24: ent "TAPE TRACK=? (0 or 1;2 if none)",r1
25: if r1#1 and r1#0;9to 29
26: trk r1
27: ent "TAPE START FILE=?",r2
28: ent "LAST DATA FILE # =?",r3
29: ent "Doppler Count Jitter=?",P[6]
30: ent "No of DCL Failures=?",P[7]
31: ent "First round no=?",P[1]
32: ent "Header=? (32char)",A$
33: prt A$
34: spc
35: ent "RF Head Offset=?",P[8]
36: ent "RF Head Setback=?",P[9]
37: fxd 2
38: prt "Offset=",P[8]
39: prt "Setback=",P[9]
40: "CMT:Read INVITE header":
41: rdb(11)+A
42: if A#32;jmp -1
43: red 11.1,P[2],P[3],P[4],P[5]
44: red 11.2,U$,P[10],P[11]
```

```
45: gto 47
46: red 11.5,U$,X,Y
47: for I=1 to 64
48: red 11.3,N[I],V[I],T[I],D$
49: D$→Q$[I,I]
50: next I
51: for I=1 to 64
52: 1→Q[I]
53: if Q$[I,I]='N';V[I]*-1→V[I];0→Q[I]
54: next I
55: "CMT:Record raw data on tape":
56: if r1=1 or r1=0;rcf r2,V[*],T[*],A$,P[*]
57: "CMT:Print parameters":
58: spc 4
59: fxd 0
60: prt "ROUND NO",P[1]
61: P[1]+1→P[1]
62: spc
63: if r1#1 and r1#0;gto 67
64: wrt 16.7,r1,r2
65: if r2=r3;1→2
66: r2+1→r2
67: fmt "DLY=",f3.0,";CNT=",f4.0
68: wrt 16,P[3],P[4]
69: fmt "Fo=",f5.0
70: wrt 16,P[5]
71: fmt "DCJ=",f3.0,";NFL=",f3.0
72: wrt 16,P[6],P[7]
73: wrt 16.9,P[10],P[11]
74: spc
75: "CMT:Print data points":
76: "CMT:Prepare data array":
77: prt "SMP  VEL    TIME"
78: wrt 16.6,U$
79: 0→N
80: for I=3 to 64
81: wrt 16.4,N[I],V[I],T[I]*1000000
82: if Q[I]=0 or N>=L;gto 88
83: N+1→N
84: V[I]→V[N]
85: T[I]→T[N]
86: 1→Q[N]
87: I→N[N]
88: next I
89: if N>=K;gto 95
90: fxd 0
91: spc
92: prt "Insufficient    samples for    analysis #=",N
93: prt "# required=",K
94: gto 141
```

```
95: if P[8]=0;9to 100
96: "CMT:Doppler Correction":
97: for I=1 to N
98: V[I]/cos(atn(P[8]/(V[I]*T[I]+P[9])))→V[I]
99: next I
100: spc
101: "CMT:Perform 1st order lst sqs fit on data":
102: 0→Q
103: 0→T
104: 0→U
105: 0→V
106: 0→W
107: for I=1 to N
108: Q+Q[I]→Q
109: T+T[I]*Q[I]→T
110: W+T[I]↑2*Q[I]→W
111: U+T[I]*V[I]*Q[I]→U
112: V+V[I]*Q[I]→V
113: next I
114: (U-V*T/Q)/(W-T*T/Q)→G
115: (V-G*T)/Q→H
116: spc
117: fxd 1
118: prt "Vo=",H,"Ao=",G
119: "CMT:Calculate residuals and stnd dev in rsdls":
120: 0→B
121: 0→R
122: 0→M
123: for I=1 to N
124: if Q[I]=0;0→R[I];9to 129
125: V[I]-(H+G*T[I])→E
126: abs(E)→R[I]
127: if R[I]>R;R[I]→R;I→M
128: B+R[I]↑2→B
129: next I
130: (B/(Q-3))↑.5→S
131: fxd 2
132: prt "SIGMA=",S
133: S*3→S
134: prt "Lgst rsdl=",R
135: fxd 0
136: prt "# lgst rsdl=",N[M]
137: prt "# of smpls=",Q
138: if R<S;9to 141
139: 0→Q[M]
140: 9to 102
141: if Z=1;beep;dsp "Targ track FULL";0→Z;wait 1000;beep;stp
142: dsp "Changes?(YE on fnc kys;NO-cont)"
143: stp
```

```
144: ato 46
145: "f0 key":
146: ent "Enter comments(32char)",C$
147: spc ;prt C$
148: ato 142
149: ent "New round no=?",P[1]
150: ato 142
151: ent "New header(32char)=?",A$
152: spc ;prt A$
153: ato 142
154: ent "New tape track(2=no tape)=?",r1
155: ato 142
156: ent "New tape file no=?",r2
157: ato 142
158: ent "New tape last data file no=?",r3
159: ato 142
160: ent "New max # of iterations=?",J
161: spc ;prt "#itrns=",J
162: ato 142
163: ent "New min # smpls to be analyzed=?",K
164: spc ;prt "min#smpls=",K
165: ato 142
166: ent "New max # smpls to be analyzed=?",L
167: spc ;prt "min#smpls=",L
168: ato 142
169: ent "New Drp Cnt Jitter=?",P[6]
170: ato 142
171: ent "New # of DCJ Failures=?",P[7]
172: ato 142
173: end
```

Special Function Keys Used
with Program 5

```
f0:  *cont 146
f1:  *cont 149
f2:  *cont 151
f3:  *cont 154
f4:  *cont 156
f5:  *cont 158
f6:  *cont 160
f7:  *cont 163
f8:  *cont 166
f9:  *cont 169
f10: *cont 171
```

B-8

APPENDIX C — ABBREVIATIONS

```
A       = ampere
Ao      = muzzle acceleration
CFK     = closed firing circuit
DCJ     = doppler cycle jitter
FOLSF   = first order least squares fit
INVITE  = initial velocity, initial trajectory evaluation system
I/O     = input/output
IRD     = infrared detect
Jo      = muzzle jerk
LED     = light-emitting diode
msec    = millisecond
mV      = millivolt
MVR     = muzzle-velocity radar
NFAIL   = number of failures
p-p     = peak-to-peak
PROM    = programmable read only memory
RAM     = random access memory
RMS     = root-mean-square
SD      = standard deviation
SOLSF   = second-order least-squares fit
TTL     = transistor-transistor logic
V       = volt
VCA     = voltage-controlled amplifier
VCO     = voltage-controlled oscillator
Vo      = muzzle velocity
```

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